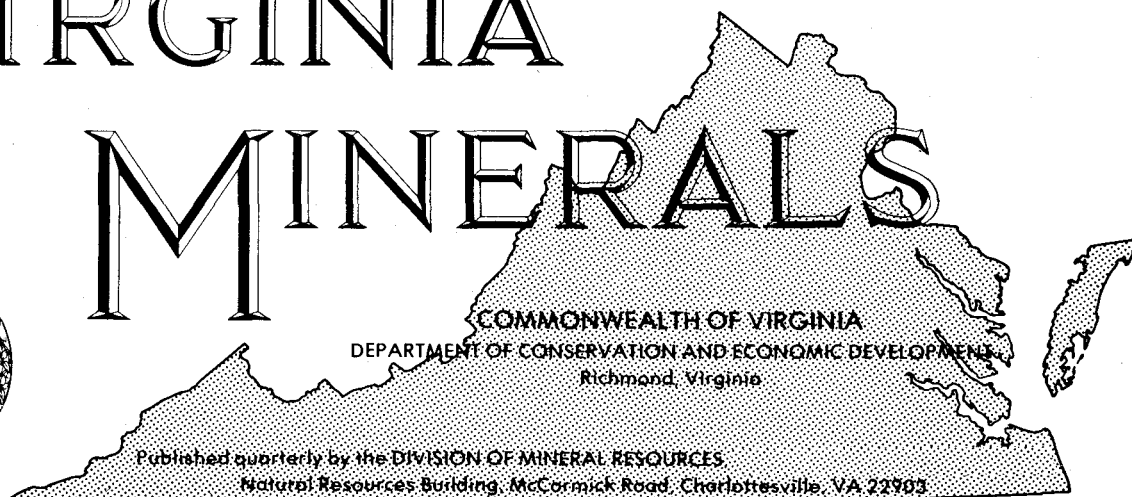


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GAS PLAYS IN OVERTHRUST BELTS: ACTIVITY IN VIRGINIA IS INCREASING

S. O. Bird

Vast blocks of onshore land are being leased in Virginia and other Appalachian states as major oil and gas companies begin what promises to be a pervasive and intensive exploration program in the Eastern Overthrust Belt. Origins of this activity and some of the obstacles to its rapid culmination in drilling programs from the Piedmont to the Plateau are discussed in this article.

Feast: Conservation of motor gasoline and other oil products began in earnest in 1979 largely as a result of the sharp increase in the price of petroleum, and helped produce a world-wide oil "glut." Several countries cut their crude oil prices in 1981 and prices were down in the world market place during most of 1981. Americans, who use a third or more (37 percent in 1978) of the oil consumed each year by the world's free countries, played a major role in these developments. Following the oil embargo year of 1974, use of motor gasoline increased until 1979 (Table 1A) when it dropped slightly, and in 1980 Americans cut their consumption of motor gasoline by 164 million barrels — a decrease of about 6 percent from the 1979 level.

This decrease is reflected in a 20 percent drop in total crude oil imports from 1979 to 1980.

These imports fell an additional 20 percent in 1981. The downward trends in use are large enough to bring about large-scale revisions in government predictions of future energy supplies. The total 1990 energy supply that was predicted in 1978 is some 15 percent higher than that predicted two years later (Table 1B). New predictions for 1990 will undoubtedly be lower on the

force of recent use curtailment and of probable future increases in prices. Many are predicting that the oil glut will end by 1984, an event that would bring an increase in today's relatively stable prices and consequent increase in conservation.

And Famine: The U. S. plans to cut oil imports substantially by 1990. When compared with the 1978 predicted need for 1990 this decrease would produce a sizeable shortfall in supply which would have to be made up from other sources. And though high prices and curtailed use continue to limit imports and to produce downward revisions in predictions, it seems certain that unless there are large new fuel discoveries or breakthrough technological developments, the U.S. will be oil and gas poor by the turn of the century. The reasons are that growth in population and industry will seek an increasing production from a dwindling reserve.

The U. S. is currently producing more than 5 times as much oil as any other noncommunist bloc nation, with the exception of Saudi Arabia, a country which produced oil during most of 1980 and 1981 at its all time high in an effort to keep pace with the demand for its oil, which was until recently priced below other OPEC oil. Production for the U. S. is now about 8.6 million barrels/day; an equal or higher production rate is predicted to continue until the year 2000. Exploration and revision of estimates of reserves in old fields have brought a near balance between reserve depletion and reserve renewal. This ratio was nearly 2 to 1 in 1979 (7 billion barrels per year depletion against 3.8 billion

Table 1A. U.S. motor gasoline use from 1973-1981. Data from Energy Information Administration (1981A).

Thousands of barrels/day					
Year	Used	Imported	Year	Used	Imported
1973	6674	134	1978	7412	190
1974	6537	204	1979	7034	181
1975	6675	184	1980	6579	140
1976	6978	131	1981	6583	161
1977	7171	217			

Table 1B. Energy supply and 1990 predictions. Values are in quadrillion Btu's. Data from Energy Information Administration (1981B).

	1978	1979	1980	1990 ^a	1990 ^b
Oil					
Domestic	20.7	20.4	20.5	23.1	19.7
Imported	17.1	17.9	14.4	17.0 ^c	11.1
Gas					
Domestic	19.5	20.1	19.7	17.4	16.0
Imported	0.9	1.3	1.0	2.0	1.0
Coal	15.0	17.7	18.9	31.2	30.3
Nuclear	3.0	2.8	2.7	9.4	8.0
Other	3.0	3.0	3.0	3.5	3.6
	79.2	83.2	80.2	103.6	89.7

^a 1978 "mid-price" estimate

^b 1980 "mid-price" estimate

^c If oil imports restricted to 8 quads as planned, a deficit in supply of 9 quads was forecasted by the 1978 prediction.

1 quadrillion Btu = 1 quad = 172 million barrels of oil = 969 billion cubic feet of natural gas = gasoline to drive 10 million cars/year.

1 barrel oil = 42 gallons = 5.63×10^3 cubic feet of natural gas

barrels per year renewal), and though depletion and renewal are now nearly equal, an imbalance toward depletion must certainly soon come about. At present the renewal rate is about 52 barrels of oil (or an equivalent amount of gas, about 300 thousand cubic feet) produced for each foot of rock drilled in the U.S. This may seem to be a substantial amount of oil and gas for the drilling, but it is only about one-sixth the value obtained in the late 1940's.

And yet the immediate best prospect for supplying the special energy needs of the U. S. now being met by oil and gas is new discoveries of domestic oil and gas. Large new oil and gas fields are being discovered in the Rocky Mountains (Western Overthrust Belt) and large gas fields are being found in the Gulf Coast (the

Tuscaloosa Trend of Louisiana and Texas), and there are significant new finds in the Valley and Ridge of the Appalachians. These strikes give hope that future discoveries will yield sufficient gas to stem imports and see the U. S. through the time from now until a new technology closes the door on the need for fuel imports. (Most of the statistical data presented in this section are from sources listed under *Oil and Gas Journal* and *Energy Information Administration* entries in "references.")

GAS AND OIL IN VIRGINIA: THE BEGINNING

Some 20 years after completion of the world's first oil well in 1859 at Titusville, Pennsylvania, drilling began in Virginia with an exploratory well in Wise County, but there was no significant oil or gas production in Virginia until 1931, when the Early Grove gas field in Scott and Washington counties was drilled following a geologic study of the area by Charles Butts (1927). Gas was produced at the Early Grove field, which is in the Valley and Ridge province, from 1931 to 1958. Production was mainly from sand lenses in the Little Valley limestone (Mississippian). Today, most gas production in Virginia is from the coalfield gas fields in the Appalachian Plateau province; production from Dickenson County currently exceeds the combined production of all other counties in the State. Production in Plateau fields is mainly from the Greenbrier Limestone (an interval including rocks equivalent in age to the Little Valley limestone), from sandstones higher and lower in the Mississippian section, and from Devonian shales (Table 2); these fields were discovered between 1948 and 1961 (Le Van, 1981).

There is currently renewed interest in the Early Grove field area and in other regions of the Valley and Ridge province. Highlander Resources Company hit one and probably two commercial gas zones in a well drilled near the center of the Early Grove field just west of the Washington County line. The deeper (about 3400 feet) of the two gas zones is the Little Valley Formation. Drilling is to continue to the Berea which is near the base of the Mississippian section at 5200 feet, according to Charles Bartlett, consultant geologist for Highlander Resources. Two old wells in the Bergton field, Rockingham County, have recently been put back into production by Scott Enterprises and two new wells in the same county were brought into production by Merrill Natural Resources of Chesterfield, Virginia in 1981 (Figure 1). Pipelines for these four producing wells have been completed.

Table 2. Highly generalized stratigraphic column for Precambrian to Lower Mesozoic rocks in Virginia.

Age	Rock Unit	Remarks
Triassic	Terrigenous clastic units, coal beds and intrusive mafic rocks	Sedimentary rocks are in grabens and half grabens formed in the Piedmont. Area undergoing active exploration for oil and gas.
Pennsylvanian	Cyclic, largely continental, sequences of sandstone, mudstone, coal	Youngest Paleozoic beds in Va., which are at the surface in S.W. part of State.
Mississippian	Various terrigenous clastic units	
	Greenbrier Limestone Several limestones	
	Little Valley Formation	Major gas producing beds in S. W. part of Va.
	MacCrady Shale	<i>Decollement zone</i>
	Price/Pocono sandstone and conglomerate; includes Berea Sandstone in subsurface	Erosion-resistant caprock of Allegheny Front at western margin of Valley and Ridge province. Berea is reservoir rock.
Devonian	Chattanooga Shale	Black shale and major source beds for Appalachian hydrocarbons. A reservoir rock.
	Oriskany Sandstone; Helderberg-age limestones and sandstones	Important reservoir rock in W. Va. and Pa.
Silurian	Salina Group limestones; salt beds in W. Va. and Pa.	<i>Major decollement zone</i> in Plateau province of W. Va. and Pa.
	Various clastics, some continental. Tuscarora Sandstone	Important reservoir rock in W. Va. and Pa. and drill-bit target in Va. Ramp zone.
Ordovician	Terrigenous clastics of Juniata/Sequatchie formations	<i>Major decollement zone</i>
	Martinsburg Fm.	
	Trenton Limestone	Main reservoir rock in Rose Hill and Ben Hur oil fields
	Various mudrocks and limestones	<i>Major ramp zone</i>
Cambrian	Beekmantown and Knox group carbonate rocks	<i>Major decollement zone</i>
	Conesauga Group and Rome Formation	<i>Major decollement zone</i>
	Shady Dolomite	
	Chilhowee Group	
Precambrian	Catoctin greenstone and other formations and rock types	Basement complex

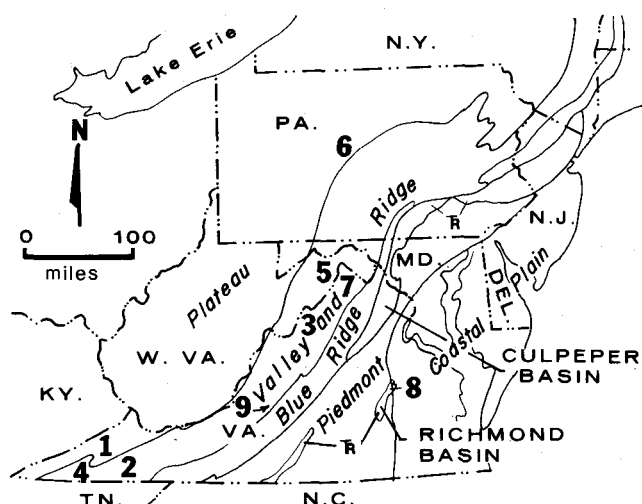


Figure 1. Oil and gas fields in Virginia, Appalachian physiographic provinces, and general areas of newly discovered gas fields and recently drilled wells. (1) coalfield gas fields, (2) Early Grove gas field, (3) Bergton gas field (Rockingham County), (4) Rose Hill and Ben Hur oil fields. Areas of newly discovered gas fields are in Mineral County, W. Va. (5) and Centre County, Pa. (6). New exploratory wells in Virginia mentioned in text are ones in Scott (2), Rockingham (3), Lee (4), Frederick (7), Chesterfield (8) and Botetourt (9) counties.

The first commercial oil production in Virginia began in 1942, when the Rose Hill field in Lee County was brought in. Later, in 1963, oil was discovered in the Ben Hur field, which is also in Lee County (Figure 1). These oil fields are the only ones in Virginia, and, more strikingly, they are virtually the only oil fields in the Valley and Ridge province. The two fields are mainly located in fensters eroded through the Cumberland thrust sheet (Figure 2). The Trenton Formation (Upper Ordovician) is the chief reservoir rock. Production from the two fields totalled about 9500 barrels for 1980. Production from beneath a major thrust sheet is something of a geologic novelty, but future exploration in the Appalachians will probably penetrate many such areas, as is discussed next.

GENERAL ANATOMY OF AN OVERTHRUST BELT

Thrust faults give silent testimony of dramatic change at the earth's surface, where the faults are recognized by the juxtaposition of rocks of unlike age and, commonly, of unlike lithology. Some of these thrust sheets are on a truly grand scale: two named for towns in Virginia, the Saltville and Pulaski thrust faults, and one named for the Blue Ridge Mountains

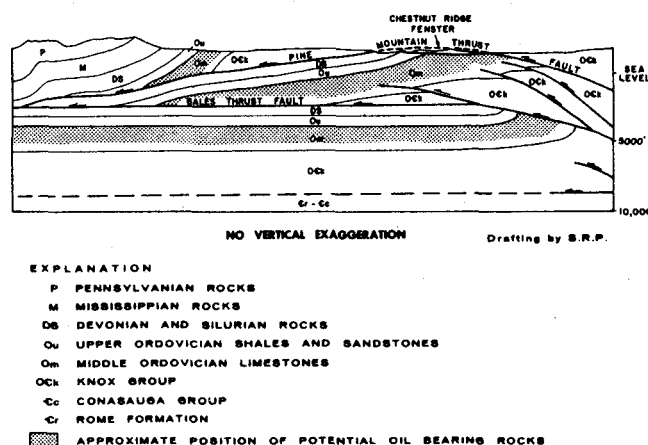


Figure 2. Generalized structure section across Rose Hill oil field (from Gathright, 1981), which lies in the area of the Chestnut Ridge fenster. The base of the Cumberland thrust sheet here is the Pine Mountain fault.

extend across several states and have displacements measured in miles.

The gigantic size of such faults is one of their features making it difficult to account for their origin. If the faults originated by horizontal compressive forces, how were the forces transmitted through relatively weak rock (weak at such scales)? Or, alternatively, did the faults arise as a result of great masses of rock sliding down a gentle incline on the force of their own weight and then piling up at the toe of the slide as age and displacement relationships among the faults seem to require (Milici, 1975)? Thus debate has centered on the origin and transmission of the forces causing rupture and displacement, and on length of displacement, place of origin or "root zone," and angle of dip of thrust sheets. Geologists aligned themselves on two sides of the fault-origin question: were the thrusts deep seated and displaced along planes with high angles of dip ("thick-skinned model") or were they shallow seated with low angles of dip ("thin-skinned model")? Evidence in support of the thin-skinned position included field observations that regionally related faults contain identical beds in the leading edge of their hanging walls—evidence suggesting that the faults arose repeatedly from a common depth. Many of the concepts on fault mechanics arose from studies on Appalachian geology. Because crystalline rocks of the basement are not included on the fault surfaces west of the Blue Ridge, it was assumed that the faults to the west in the Appalachians were shallow seated. In contrast, two main observations comprised evidence that seemed to support a deep-seated origin of thrusts and associated structures: thicknesses of some sedimentary units in-

crease toward centers of certain synclines (which supported the idea that folds grow through long intervals of geologic time), and depth to the crystalline rocks forming the basement is somewhat variable (which seemed to show that some folds extend to basement). From these observations it was inferred that thrust faults were deep seated and that they generally post-dated folds.

Deep drilling first and geophysical data (mainly seismic) second, pretty well put the matter to rest in the Appalachians, and elsewhere, for thrust faults were shown by drilling in West Virginia, Virginia and Pennsylvania to underlie folded beds similar to those in the Valley and Ridge province and to overlie flat-lying beds typical of the Plateau province (Gwinn, 1964). Seismic data have recently been used to illustrate that these relationships extend throughout the Appalachians (Milici and others, 1979; Cook and others, 1979; and Harris and Bayer, 1979), and in other mountain chains, throughout the world.

A major piece of the puzzle explaining the forces producing thrust faults was supplied by Hubbard and Ruby (1959) and Ruby and Hubbard (1959), who presented compelling evidence that these faults could originate along impervious and incompetent beds such as shales and salt beds on gentle slopes under the force of the weight of the rocks above them. This was an especially welcome idea because it was such impervious and incompetent rocks that had long been known from field mapping to be on the hanging walls of thrust faults. And it was these beds that were later shown by drilling to lie beneath areas of deformed rock and above areas of undeformed rock. The gravity slide theory did not require rocks to transmit deforming forces to the area of rupture.

As these ideas of the origin of thrust faults became part of the thinking of many geologists, the whole concept of how the folds of mountain chains such as the Appalachians are formed began to undergo profound change. During this time of revolution in geologic thinking, the ideas of Rich (1934), who presaged these new concepts, were "rediscovered." One major idea of the new concepts is that rootless folds form as a result of displacement on thrust faults, indeed the idea has become one of the empirical "rules" of thrust belt structural geology. This and other rules have been summarized by Royse and others (1975); Harris and Milici (1977); Allmendinger (1981); and others. Some of the relationships are shown in Figure 3; these include the idea that many folds in thrust belts are produced by faults, that synclines are passively formed as a result of displacement that forms anticlines adjacent to them, that structures above and below decollements are unequal to each other, and that decollements are in incompetent beds and that ramps are in competent ones. The importance of these relation-

ships to exploration for oil and gas will be evident in the following discussions. One important consequence of the idea that anticlines (the major structural oil and gas trap) are produced by faults is that they do not extend below the decollement forming them.

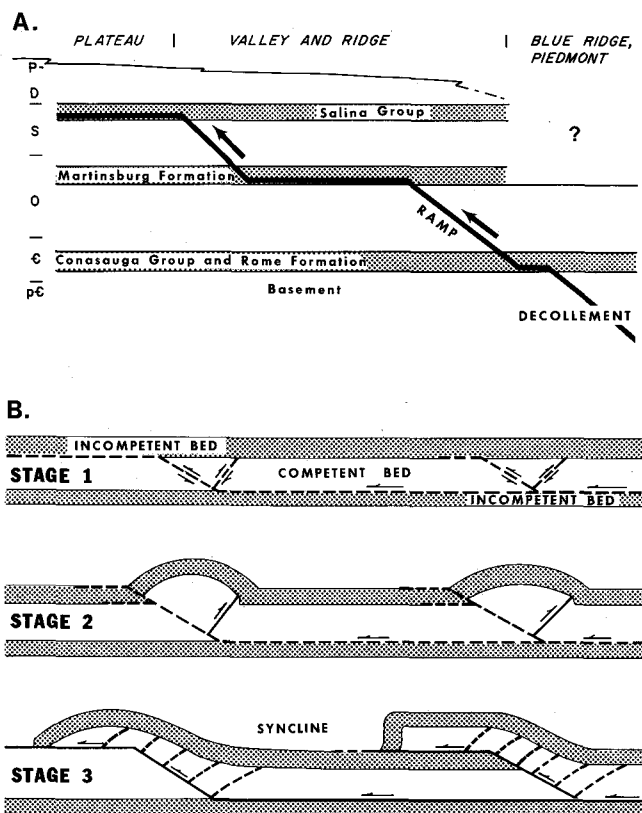


Figure 3. Simplified, conceptual diagrams of decollements and attendant structures. A. "Major Appalachian decollement" lies within incompetent and impervious rocks such as shales and salt beds, and "ramps" across incompetent beds such as sandstones and limestones; the thrust lies at successively higher stratigraphic zones in the direction of motion. Stratigraphic symbols are P, Permian; D, Devonian; S, Silurian; O, Ordovician; C, Cambrian; pC, Precambrian. The Upper Devonian to Lower Mississippian interval also is a major fault zone. B. Anticlinal and synclinal structures formed by thrusting. Anticlines here result from thickening of the incompetent bed and by growth of reverse faults, which originate near the toe of the ramp zone and migrate up it (Morse, 1977). The resulting convex-upward form extends to higher strata. Synclines are passively formed between anticline, according to these ideas. Continued movement along the decollement generally results in complex arrangement of rocks, — see, for example, Milici (1962). The E-W distance in Figure 3B is a few tens of miles. See Table 2 for notes on rock units.

OVERTHRUST BELTS AND HYDROCARBONS

The West: Oil and gas prospects in overthrust belts have not long been viewed with enthusiasm, for though there has been sizeable hydrocarbon production beginning in the 1920's (and beginning to boom in the 1950's) from the Rocky Mountain foothills in Alberta, an area which forms a tiny part of the Western Overthrust Belt, extensive exploration in geologic similar areas in Montana, Wyoming and Utah failed in discovery of significant hydrocarbon resources until recently. The Western Overthrust Belt extends from Alaska into Mexico. Discovery of oil and gas in the U. S. part of the Belt began in the 1950's, but it was American Quasar's 1975 discovery of the Pineview oil field in Utah and Amoco Production Company's 1976 strike some 40 miles to the north at Ryckman Creek, Wyoming (Figure 4), that spurred the feverish play now in progress in the Western Overthrust Belt of the U. S. Discovery in the U. S. has so far been mainly in the Utah-Wyoming segment of the Belt; in five years (1975-1980) the 50-mile-long segment yielded twelve commercial fields in Utah and Wyoming (Figure 4). Five of the fields are defined as giant fields, ones with recoverable reserves of at least 300 billion cubic feet of gas or 50 million barrels of oil. Most wells in the region are more than 13,000 feet deep. Eleven of the twelve fields are in anticlines, which presumably developed during thrusting in the

hanging walls (upper sheets) of two (the Absaroka and Twp) of the six major thrust faults of the Western Overthrust Belt (Anschutz, 1980). There are at least seven productive formations in the anticlines and this gives prospectors hopes of discovering huge fields. Reservoirs in the region are Mesozoic and Paleozoic rocks of the upper thrust sheet which are juxtaposed with source rocks of Cretaceous age in the subthrust sheet; the Nugget Sandstone (Jurassic) is a prime target of the drill bit. As we shall see, there are several reasons why prospectors are not so hopeful for giant fields in the Eastern Overthrust Belt.

Exploration in the Western Overthrust Belt has recently been extended to the far southeastern reaches of the U. S. part of the Belt, where drilling is underway in Arizona and New Mexico. Some geologists are predicting that reserves in the Belt will eclipse those at Alaska's Prudhoe Bay, which holds 9.5 billion barrels of oil and 29 trillion cubic feet of natural gas (McCasin, 1980A). Significant gas production from Alaska will not begin until pipelines to the U. S. are completed.

The East: It was largely discoveries in the Western Overthrust Belt, and the general similarity of the geology of this Belt to what is now being called the Eastern Overthrust Belt, that stimulated the broad exploration efforts underway in the Appalachians. The factors which led to discoveries of hydrocarbons in the West (economic incentives, improved seismic technology as well as more abundant data, and a new understanding of geologic structures) are at work in the promotion of exploration in the East. Virtually all of the oil and most of the gas produced in the Appalachians has come from the Plateau province, an area once thought to have undergone little tectonic upheaval. Data from drilling projects, seismic reflection studies and geologic mapping show that all or much of the Plateau province in Pennsylvania, West Virginia, and Virginia lie above a decollement in Upper Silurian salt beds (Gwinn, 1964; Milici, 1980) or in shales of equivalent or somewhat younger age. Thus the gas and oil produced from the Plateau province of these states are from structures lying above a major decollement.

The part of the Eastern Overthrust Belt (Figure 5) of prime interest for oil and gas exploration extends a distance of about 1100 miles from New Jersey to Alabama. It is probable that most oil and gas exploration and production in the Appalachians will continue to be from the Plateau province, which in 1976, the latest year for which state data are available, produced about one and one-half percent of the Nation's natural gas, but there is mounting interest in Valley and Ridge and even in Blue Ridge and Piedmont areas. Commercial quantities of gas may exist in association with Mississippian-age coal beds in the Valley and Ridge province. A test well to be drilled in 1982 by the Virginia Division of Mineral Resources in Montgomery County

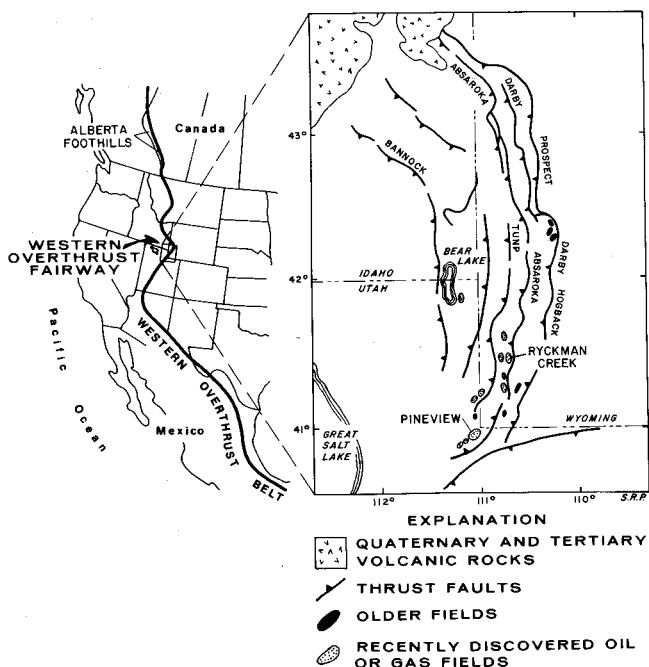


Figure 4. The Western Overthrust Belt (after Anschutz, 1980).

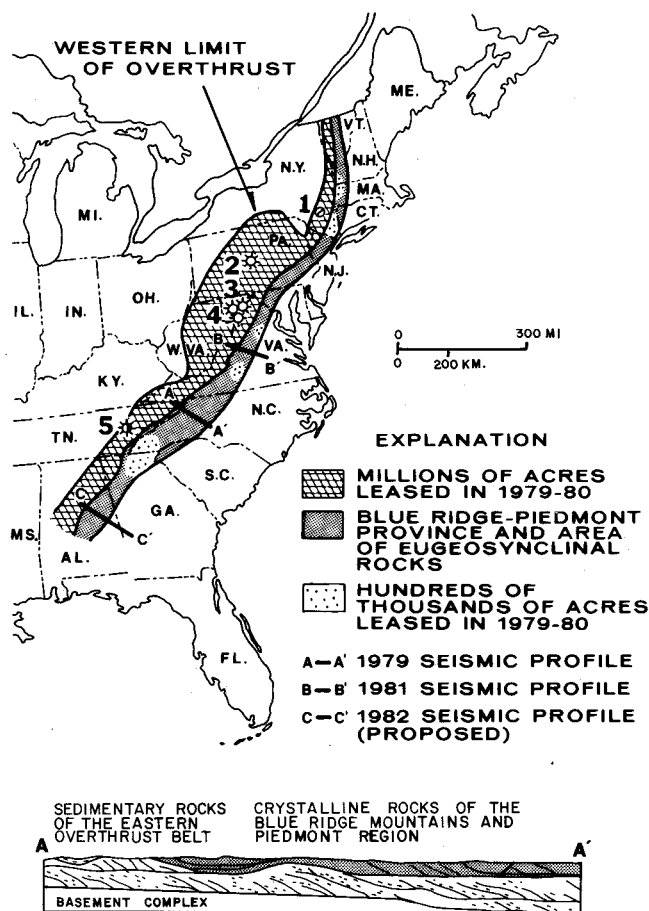


Figure 5. The Eastern Overthrust Belt (after Crow, 1981). Wells and fields indicated by numbers are (1) ARCO 1 Susi; (2) Amoco's Devils Elbow fields; (3) Columbia's Mineral County wells; (4) Exxon 1 Bean.

near Blacksburg, Virginia has been funded by a grant from the Department of Energy. The hole is planned for a depth of 3000 feet; it will penetrate the Pulaski thrust sheet and coal-bearing Mississippian strata beneath the sheet.

PROSPECTING IN VIRGINIA: THE FUTURE

A small part of Virginia lies within the prime oil and gas area of the Appalachians, the Plateau province, and this is the area of greatest gas production in Virginia (Figure 6). There is currently small production from the Valley and Ridge of Virginia, but it is in this area that exploration is likely to be most intense in the State.

Before proceeding with notes on these prospects, it is well to look at some negative factors bearing on exploration in Virginia and in the Appalachians in general.

Economic factors:

- U. S. drilling and completion costs in 1980 were up 41.2 percent from 1979; the average cost of drilling per foot in 1980 was nearly \$68, up by almost \$10 from the 1979 value (McCaslin, 1981). Drilling costs in the Appalachians are generally high because of the common occurrence of well-indurated sandstones that are difficult to drill through, the need to bring in rigs from outside the area, and other factors including those resulting from the effects of rugged terrain and dense vegetation; an 8,000-foot well in the Appalachians costs the same as a 15,000-foot well in Oklahoma.
- Many wells in the Valley and Ridge of Virginia and elsewhere in the Appalachians may need to be drilled to depths of 11,000 to 12,000 feet; the current cost of such wells is expensive at 2½ to 3½ million dollars (Crow, 1981).
- Many productive wells will not be so deep as 15,000 feet and gas from them therefore will not qualify for price deregulation provided by Section 107 of the 1978 Natural Gas Policy Act. The Federal Energy Regulation Commission can and does deregulate gas prices from "tight" rocks, ones with low porosity, on an *ad hoc* basis, but resulting prices are not nearly so attractive as those from rocks below 15,000 feet. Deregulation from other high cost sources and general deregulation will not likely soon take place (Jennrich*, 1981), and, accordingly, high production costs and risks in the Appalachians will not soon be matched by high sales prices.
- Gas can be obtained from Canada, and will likely soon be available from the Western Overthrust Belt in Mexico, that is cheaper than domestic gas from deep wells.
- More than 300 dry wells were drilled in the U. S. part of the Western Overthrust Belt before there was a significant discovery.

Geologic factors:

- Intergranular porosity is low in Valley and Ridge rocks and production may depend heavily on the number and spacing of fractures in reservoir rocks, both of which are generally unknown prior to drilling the rocks.

*In a more recent article, Jennrich (1981b) states that a probable federal government need for additional revenue may result in gas deregulation so that a windfall tax can be levied on it.

- It is likely that gas and not oil will represent hydrocarbons in the Valley and Ridge, for conodont color alteration indices indicate that rocks in the province were cooked at temperatures and pressures generally too high (hydrocarbons are too mature) for oil to be preserved (see Harris and Milici 1977).

In summary, then, it can be said that in spite of similarities between structures of the Appalachian and Rocky Mountains, prospects in Virginia, as well as in other Valley and Ridge areas of the Appalachians, are not quite so bright as in the Rockies. "Deficiencies" in the Valley and Ridge include the relative antiquity of the rocks and a related high maturity of hydrocarbons in them; tight cementation of potential reservoir rocks and consequent loss of intergranular porosity in these rocks; a relatively small number of source beds, which are fault-omitted in some places otherwise suitable as prospects; and a relatively small number of reservoir beds, which are generally widely, rather than closely, vertically spaced. In addition, exploration is more difficult in the East than in the West because rocks with high seismic wave velocities lie near the surface in the East (limestones and indurated sandstones in the Valley and Ridge provinces, and a variety of metamorphosed rocks in the Blue Ridge — Piedmont provinces). Where such rocks overlie ones of lower velocity, seismic waves are sent deeper into the earth rather than being reflected back to the surface, and reflection records are correspondingly more difficult to interpret with precision. Differences between East and West in terrain and vegetation are also in favor of profitable exploration in the West.

Impetus: Against these negative factors is one fact: six new gas wells in and just west of the Valley and Ridge province give promise of big strikes and fuel the hope of discovery in the Eastern Overthrust Belt just as the Pineview strike did in its western counterpart. Three of the six wells (Figure 6), which were all wildcats, were developed by Amoco, perhaps the most active exploration company in the Western Overthrust Belt and a major landholder in the East. The three Amoco wells were completed in 1977 in Centre County, Pennsylvania; total natural gas flow is 9.5 million cubic feet per day (MMcfd). Two of the wells are in the Tuscarora (Silurian) and one is in the Oriskany (Devonian). The other three wells were drilled by Columbia Gas Transmission Corporation in Mineral County, West Virginia. Gas flow rate in two of these wells, completed in 1978 and 1980 in the Oriskany, totals 17.8 MMcfd (Crow, 1981). The giant of the six wells was completed by Columbia in 1981 in the Tuscarora; gas flow rate is 88 MMcfd, according to

Mr. B. T. Fulmer, State Oil and Gas Inspector. (Stratigraphy is shown in Table 2.)

On the strength of these discoveries, leasing activities in the Appalachians has become hectic as companies struggle to fill in their holdings. At present, more than 3 million acres in Virginia have been leased for oil and gas exploration.

To Action: Several exploration and development wells have been completed in the Valley and Ridge of Virginia. Mr. Fulmer reported that two new field wildcats recently completed by Amoco, one in Frederick County, and one in Rockingham County, were dry holes. The target in each well was the Tuscarora Sandstone. Four wells, three development and one new field wildcat, were drilled in Rockingham County by Merrill Natural Resources. Two development wells were completed in the Oriskany Sandstone; the wildcat and one development well were dry holes. Farther south, near Gaylor in Botetourt County, Columbia Gas and Transmission Company has just finished drilling a dry hole below the Tuscarora, the original "target" in this stratigraphic test well.

Highlander Resources drilled 7140 feet through a thick Mississippian section in reaching the Berea Sandstone (Mississippian) in the Greendale syncline in Washington County. There was a gas flare, flow of gas from the well, when drilling entered the Little Valley Formation, and there was a gas show in the overlying Fido Sandstone. Work is now underway to determine if there are commercial quantities of gas in the well.

In 1981, 66 permits for drilling oil and gas wells in Virginia were issued—a number nearly one and one-half times as large as the total number permitted in the State in 1980. Fifty-three oil and gas wells were drilled in 1981 and 22 were completed as producers; the corresponding figures for 1980 were 25 and 20. Most of the 1981 permits were for the coalfield area in the Plateau, but one well, being drilled by Atlantic Richfield Company, is going to basement at about 16,000 feet in the Valley and Ridge of Lee County. The well should traverse the Pine Mountain and Bales thrust sheets and will add much information on the structure of the rocks in the Ben Hur and Rose Hill oil fields.

Even the Blue Ridge and Piedmont provinces have a potential for oil and gas production on the basis of recently gathered data, which consists of seismic lines completed by the Consortium for Continental Reflection Profiling (Cook and others, 1979), the U. S. Geological Survey (Harris and Bayer, 1979), the Department of Energy, with the Tennessee Geological Survey (Milici and others, 1979), and others in the Appalachians of the U. S. and one drilling project in Quebec. There is compelling evidence that rocks belonging to the Blue Ridge and Piedmont provinces

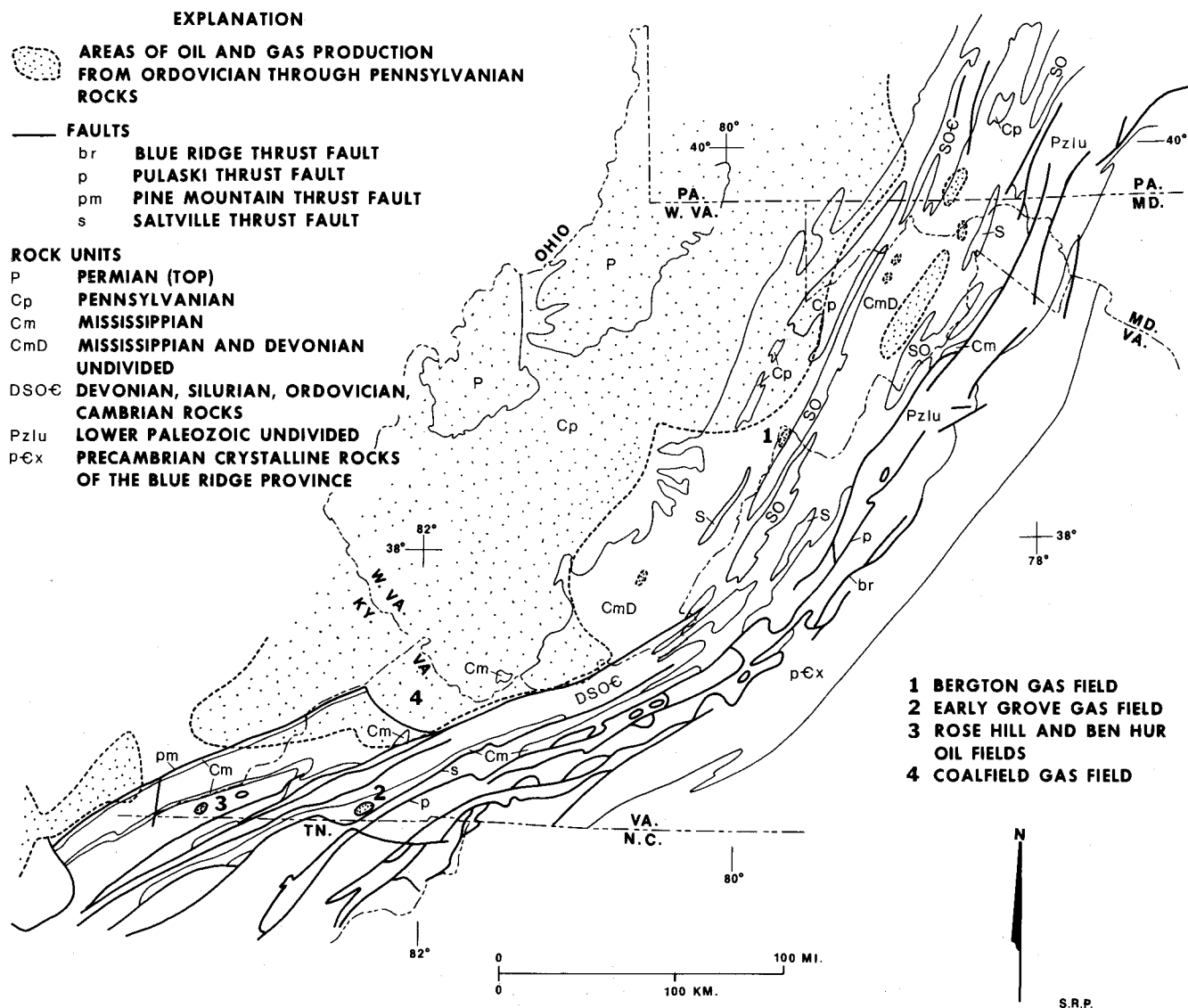


Figure 6. Generalized map of geology in part of the Eastern Overthrust Belt (after Milici, 1980). Most of the known gas and oil of the area lies west of Virginia. The great bulk of the gas produced in Virginia is from Lower Mississippian units, and areas where these rocks lie along thrust faults are good gas and oil prospects at depth on the fault footwall. At places on the figure, rock unit symbols are used in different combinations than is shown in the legend.

from Georgia to North Carolina and other eugeosynclinal rocks north to Quebec have been thrust over miogeosynclinal rocks of the Valley and Ridge province. Thus the Piedmont province constitutes a crystalline rock "veneer," in places from about 2.5 to 11 miles thick, overlying a much thinner section of chiefly Lower Paleozoic sedimentary rocks. The root zone of the thrust is not known, but the master decollement in the Southern Appalachians, and perhaps to the north as well, is interpreted by Harris and Bayer (1979) to

extend from the continental shelf west through the Appalachian Plateau (Figure 3A). Seismic lines completed in June 1981 by the U. S. Geological Survey extend from Staunton to Norfolk along Interstate Highway 64 (line "B" in Figure 5). The line will provide abundant data on Valley and Ridge, Piedmont, and Coastal Plain structure and geologic history. Meanwhile leasing is active all along the foothills east of the Blue Ridge Mountains, as some oil companies prepare to drill in the area in an effort to find a strike in

the unmetamorphosed Paleozoic rocks lying beneath the Blue Ridge overthrust.

One region of the Virginia Piedmont is now being drilled for gas and oil, this is the Richmond Triassic basin in or near Chesterfield County (Figure 1). According to Dr. Bruce Goodwin, Consulting Geologist for Merrill Natural Resources, six holes have been drilled by the company a few miles west of Richmond in the basin. The wells have reportedly penetrated rocks with significant quantities of gas, a "good quality of oil," and several coal beds—one is eleven feet thick and three together total 20 feet. The gas is associated with the coal beds and with dark organic shales; the oil is in sandstones. Oil was known to be in these rocks as early as 1878 when it was observed seeping through outcrops of sandstone. Gas, like oil, was known to be in the rocks, because at times when the coal was being mined in about 1810, there had been methane explosions in the mines; in addition, a group called the Richmond Syndicate drilled seven wells in 1931 and reported "shows" of both oil and gas (G. Wilkes, personal communication, 1981).

If commercial quantities of gas are found in the Richmond Triassic basin, rapid exploitation is favored by the proximity of distribution lines leading to Richmond, reservoir depths of less than 2500 feet, and a gas flow that can probably be cheaply increased by hydrofracturing the rock down the well.

In addition to Merrill, at least two other oil companies and their leasing affiliates are in the area. One, Charles J. Maurer Oil Properties Inc., an exploration arm of Cornell Oil Company, is now drilling its third hole in the Richmond basin; its earliest drilled two wells are being evaluated by the Company. Merrill has a \$78,000 grant from the Department of Energy under its Unconventional Energy Sources program to drill a deep well (2500 feet) near Salisbury, and the Company is awaiting arrival of a deep-drilling rig to finish one of its existing wells. Leasing activities are vigorous.

Excitement is mounting in Virginia as major oil companies, along with some minors, explore long forgotten potential in the Triassic basins and attempt to widen the fairway of the Eastern Overthrust Belt. Demand for hydrocarbons can only increase until the time these fuels are replaced by new energy sources. The tools for exploration are sharp enough for the task of finding the deeper fields in the complex structural areas that will provide much of the U. S.'s new reserves, and a year or two of drilling should do much to establish the onshore hydrocarbon potential for Virginia by determining if the gas and oil of the Plateau and western part of the Valley and Ridge are preserved in rocks of the same age farther east (Figure 6).

CONCLUSION

An enormous drilling effort is being conducted onshore in the U. S.; more than 9 million feet (1700 miles) were drilled in 1980 for exploration, development, stratigraphic and service wells, an eleven percent increase over the 1979 record-setting footage. The 1980 footage drilled in search of new fields was an all time record, and for dry holes it fell just short of the 1956 record. Most of the wells (a predicted 77 percent in 1981) were drilled by independent oil companies. In spite of these efforts, the U. S. production/reserve renewal ratio would be greater than one if it were not for revisions in estimates of reserves in old fields. New discoveries account for only about 29 percent of the amount of oil and gas needed to balance production (about 8.6 million barrels/day) against renewal (*Oil and Gas Journal*, 1981 C); the remainder of the balance (71 percent) is a matter of bookkeeping.

And even as this drilling effort continues, predicted energy needs are being revised sharply downward. A recent prediction of the needs for the year 2000 is only 99 quads, a figure substantially less than the 1978 prediction for 1980! These projections along with new discoveries in the U. S. and in Mexico and Canada are the most encouraging trends in energy supply that have come forth in a long while, though the downturn in use promises to choke off some of the federal and state tax revenue on oil, gasoline and natural gas, a wellspring that has been especially heavily counted on by the federal government. If new discoveries of oil and gas continue at the predicted rate, and if present conservation trends continue, the world should get through the year 2000, at least, without severe hardships arising as a consequence of oil and gas depletion (though there may be severe politically imposed shortages). Three factors threaten to reverse the conservation trend, however: loss of public concern (as indicated by a marked upturn in gasoline consumption in the late months of 1981), predicted decreases in real costs of oil, and possible government promotion of use.

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AUSTINVILLE MINE CLOSES

The New Jersey Zinc Company, a division of Gulf and Western Industries, Inc., ceased operation of their Austinville lead-zinc mine in Wythe County December 31, 1981. Having been active for 225 years, the Austinville mine was the oldest continuously operating mine in the United States and was the only active metal mine in Virginia. It employed approximately 200 persons and had an annual payroll of several million dollars before production was halted November 13, 1981.

An estimated 30 million tons of ore has been extracted from the mine workings which extend approximately six miles along strike and one-half mile across strike. An estimated 900,000 tons of reserves were on the books at the time of closing.

During operation 13,000 gallons of water per minute were pumped from the mine. As mining and pumping cease, an estimated billion gallons of ground water will flood the shafts and drifts. The flooding is expected to take about a year, and when full, the mine will contain enough water to produce a 265 acre lake, ten feet in depth. This underground water storage system has potential as a valuable reservoir in the future.

Lead from this mine was used to make ammunition for the firearms of pioneers, the Colonial Army, and the Confederacy and to cover the second roof of Virginia's Capitol in 1789-1790.

COAL RESOURCES STUDY

The Division has begun calculating coal resources for Lee, Wise, Dickenson, and Scott counties. This estimate of resources will be the newest resource data since the 1952 estimate by Brown and others. Resource calculations will be made with the cooperation of the U.S. Geological Survey who will calculate resources in Buchanan, Russell, and Tazewell counties.

Information on bed thickness, stratigraphic position and extent of mining has been collected during the past two years from a number of sources. These data have been entered into a computer data base and the resource calculations will be done on the computer. In addition to resource estimates, regional structural and stratigraphic studies will be possible using the computerized data base.

NEW PUBLICATION

Publication 33, — Analyses of Coal Samples Collected 1975-77 by Henderson, Oman, and Coleman, is available by mail for \$4.62 from the Division.

Chemical analyses were performed by the U.S. Bureau of Mines and the U.S. Geological Survey. The U.S. Bureau of Mines analyses include proximate and ultimate analyses, forms of sulfur, heat value, fusibility of ash and the free swelling index.

The U.S. Geological Survey analyses include the major-, minor-, and trace-element concentrations in both ash and whole coal. Statistical tables contain arithmetic and geometric means, observed range, and the standard deviation for samples collected in Virginia and are compared with samples in the National Coal Resources Data System for Tennessee, Kentucky, and West Virginia.